1 B Multiple-Choice Explanations

1. The answer is A. Uniformly accelerated motion from rest means $\Delta x = \frac{1}{2}at^2$, the graph of which is a concave up parabola.

2. The answer is D. The velocity decreases linearly, $v = v_0 - gt$, and so does the momentum, since $p = mv$.

3. The answer is D. Newton's third law tells you that the force exerted by the book on the Earth will equal the weight of the book. This is the reaction force to the weight, not the normal force. Since the book isn't accelerating, the normal force and weight have equal magnitudes.

4. The answer is D. The acceleration due to gravity is constant and directed down the entire trip.

5. The answer is E. Applying the second law to the entire system, you have
   $m_1 g = (m_1 + m_2)a$

6. The answer is D. Gravity and the spring force are in equilibrium.
   $k(0.05) = (0.25)(10)$

7. The answer is B. Momentum is conserved, but there is more kinetic energy after the collision than before, so it must have come from some stored potential energy. Elastic collisions conserve KE, and this obviously does not.

8. The answer is B. There must be a component forward to accelerate the 4 kg mass, and a component upward to balance gravity.

9. The answer is E. The normal force between the two masses is the only force accelerating the 4 kg mass, so $N = ma = 4(15) = 60$ N. The static friction provided is less than or equal to the maximum value, but it must equal the weight to keep from slipping.
   $f = mg = 40 \leq f_{max} = \mu N = 60\mu$

   $$\mu \geq \frac{2}{3}$$

10. The answer is A. Taking torques about the pivot, you have
    $net\tau = 0 \Rightarrow 40\sin30(2) - F(0.5) = 0$

11. The answer is E. The work done by friction will equal the change in mechanical energy.

$$\Delta E = mgh - \frac{1}{2}mv^2 = 40(3) - \frac{1}{2}(4)(10^2) = -80 \text{ J}$$

12. The answer is C. The average power is the increase in PE divided by the time it takes.

$$P = \frac{mgh}{t} = \frac{(600)(12)}{10} = 720 \text{ W}$$

13. The answer is B. Both N and mg act down, so the second law gives you

$$N + mg = \frac{mv^2}{R}$$

14. The answer is B. The normal force at P is supplied by the normal force because gravity has no component to the center. The normal force here depends on the speed, so there's no reason for a relation between the weight and the normal force.

15. The answer is E. The electrons on the neutral conductor will move toward the nonconducting sphere. While the conducting sphere remains overall neutral, the closer negative charges will lead to a net attractive force.

16. The answer is B. The horizontal component to the right from $+Q$ is larger than the horizontal component to the left from $-Q$. The $-Q$ creates an upward vertical component.

17. The answer is D. The center is equidistant from the two equal but opposite charges:

$$U = k\frac{qQ}{a\frac{\sqrt{2}}{2}} - k\frac{qQ}{a\frac{\sqrt{2}}{2}} = 0$$

18. The answer is A. The field will be greatest where the surfaces are closest, since

$$E = \frac{\Delta V}{\Delta x}$$

19. The answer is C. It takes no work to move through 0 potential difference.

20. The answer is E. At C, the field is perpendicular to the surface and directed toward lower potential. Electrons will accelerate opposite the field direction.

21. The answer is D. Current is charge per time, and the charge on an electron is 1.6×10^{-19} C.

$$I \cong \frac{10^8 \cdot 10^{-19}}{10}$$

22. The answer is A. The fluid pressure is $\rho gh = \rho(50) = 3 \times 10^4$.

23. The answer is D. By Archimedes' principle, the mass of the solid equals the mass of the displaced fluid: $m = \rho_f hA$. The volume V of the solid is just tA, so $\rho_{solid} = \frac{m}{V} = \rho_f \frac{h}{t}$.

24. The answer is B. The weight of the displaced fluid will be the difference in the two spring force readings: $k(x_1 - x_2) = \rho_f g V$. Solving for V gives the result.

25. The answer is B. Pascal's principle tells you that any change in pressure applied to an enclosed static fluid is transferred undiminished throughout the fluid.

26. The answer is E. Adiabatic means no heat transfer, so the first law gives you $\Delta U = Q + W = W$. The internal energy has increased, and for an ideal gas, this means the temperature must increase as well, since $\Delta U = \frac{3}{2}nR\Delta T$.

27. The answer is E. By Archimedes' principle you know that an object placed in a fluid and allowed to reach equilibrium will displace an amount of water having a weight equal to the object's weight, so II is true. If the object had a greater density than the fluid, then even when completely submerged the weight of the displaced water would be less than the weight of the object and the buoyant force would not be great enough to keep it afloat. Thus I is true. If the object is completely submerged, for example by pushing it under the surface, it must displace a volume of water equal to its own volume, so III is true.

28. The answer is A. Bernoulli's principle, $\frac{1}{2}\rho v^2 + \rho g h + p =$ constant, follows from energy conservation.

29. The answer is A. Number I is heating by radiation, and III is by conduction. Number II is a work process.

30. The answer is D. In an ideal gas, after the molecules separate they exert no force on each other. Clearly, charged electrons will exert repulsive forces on each other.

31. The answer is B. Since $U = \frac{3}{2}nRT$, isothermal—no change in temperature—means the internal energy stays the same as well.

32. The answer is D. Once the object is inside the focal length, a converging mirror cannot bring the rays together to form a real image. The image will always be larger than the object. A couple of test sketches would convince you of this without the need for algebraic details.

33. The answer is B. A diverging mirror will produce only a virtual image smaller than the object, as you could see with a couple of test sketches.

34. The answer is D. The image equation at the first position gives you

$$\frac{1}{f} = \frac{1}{2f} + \frac{1}{s_i} \Rightarrow s_i = 2f \Rightarrow m = -1$$

At the second position, you get

$$\frac{1}{f} = \frac{2}{3f} + \frac{1}{s_i} \Rightarrow s_i = 3f \Rightarrow m = -2$$

There is no change of image type until the focal point is passed.

35. The answer is C. A single diverging lens can produce only a virtual image. A quick sketch can convince you of the size change, or you could do the little bit of algebra using the image equation, as in question 34.

36. The answer is E. To reach threshold, you must increase the energy of the incident photons, which means decrease λ.

37. The answer is A. Since the De Broglie wavelength is much smaller than the slit size, there is very little diffraction and the electrons behave as particles, producing the particle pattern on the screen.

38. The answer is A. Writing the equation, you have

$$^{10}_{5}\text{B} + ^{A?}_{Z?} \rightarrow ^{7}_{3}\text{Li} + ^{4}_{2}\text{He}$$

Balancing top and bottom gives you $Z = 0, A = 1$.

39. The answer is C. Since neutrons are $^{1}_{0}\text{n}$, you need 2 to balance the top numbers.

40. The answer is B. Since power is $P = Fv$, you have $P = (mg)(gt) = mg^2t$. This is a linearly increasing graph.

41. The answer is D. The falling object will have a speed of $v = gt = 10(1) = 10\ \frac{\text{m}}{\text{s}}$ after 1 second. Momentum conservation then gives you $2(10) = 5v$

42. The answer is A. Use kinematics to find a and the second law to find F.

$$v = v_0 + at \Rightarrow 3 = 10 + 2a \Rightarrow a = -3.5\ \frac{m}{s^2}$$
$$F = ma = 4(-3.5) = -14\ \text{N}$$

43. The answer is B. Use momentum conservation for each component.

$$4(10) = 5v_x \Rightarrow v_x = 8\ \frac{\text{m}}{\text{s}}$$

$$1(40) = 5v_y \Rightarrow v_y = 8\ \frac{\text{m}}{\text{s}}$$

$$v = \sqrt{8^2 + 8^2}$$

44. The answer is E. The center of mass will remain stationary. Since the 6 kg mass is 3 times the mass of the 2 kg mass, it must travel $\frac{1}{3}$ the distance that the 2 kg mass travels.

45. The answer is D. The angular momentum is given by $l = mvr_{\perp} = 2(7)(3)$. If you extend the line of the velocity, $r_{\perp}$ is the closest distance to the origin of the line.

46. The answer is A. You could work out the math or recognize that the two 4 Ω in parallel will give 2 Ω, and adding a 100 Ω in parallel won't change it much.

47. The answer is B. The overall resistance of the circuit is 10 Ω, so a current of 5 A flows. The battery has a terminal voltage of $V_T = 50 - 5(2)$.

48. The answer is A. The 5 A will split into a 4:1 ratio at the junction with 4 A going through the 5 Ω resistor, so $P = i^2R = 4^2(5) = 80$ W.

49. The answer is E. Starting at A, you go up 40 V through the battery, its terminal voltage, then down $V_{12} = 1(12) = 12$ V through the 12 Ω resistor, which carries 1 A.

50. The answer is D. The continuity equation tells you that $v' = v\frac{A}{A'} = 3\frac{4^2}{1^2} = 48\ \frac{\text{m}}{\text{s}}$.

51. The answer is B. Use Bernoulli's principle on opposite sides of the hole.

$$\left(\frac{1}{2}\rho v^2 + \rho gh + P\right)_{out} = \left(\frac{1}{2}\rho v^2 + \rho gh + P\right)_{in}$$

$$\frac{1}{2}(1{,}000)v^2 + 10^5 = 3 \times 10^5 \Rightarrow v = 20\ \frac{\text{m}}{\text{s}}$$

52. The answer is C. Since $\Delta U = \frac{3}{2}R\Delta T$, you can use the gas law to find ΔT.

$$\Delta T = \frac{\Delta p V_1}{R} = \frac{p_1 V_1}{R}$$

53. The answer is D. It is the area under the ST segment.

54. The answer is D. Each box has an area of $p_1 V_1$, and there are about 3 boxes contained inside the cycle.

55. The answer is D. When a ray of light goes from a lower index region to a higher index region, like air to glass, the light slows down and the wavelength decreases as it bends toward the normal line. Just the opposite happens as the ray exits the glass back into air.

56. The answer is D. At first interface, light bends toward normal, so $n_2 > n_1$. At second interface, it bends away from normal, so $n_3 < n_2$. If $n_1 = n_3$, the outgoing ray would be parallel to the original ray. Since it is bent beyond parallel, $n_3 < n_1$.

57. The answer is C. Since the difference in the index of refraction at the interface has decreased, there is less refraction and the angular spread is less, but the order stays the same.

58. The answer is C. The distance from the center of the Earth has changed by less than 1 percent, and this is the important distance in determining the force exerted by the Earth on the object.

59. The answer is B. The oscillating system is 4 kg, so the period formula gives you

$$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{4}{64}} = \frac{\pi}{2}$$

60. The answer is B. Use momentum conservation to find the speed after the collision, then energy conservation to find the maximum compression, which is the amplitude.

$$P_i = P_f \qquad E_i = E_f$$

$$2(4) = 4v \qquad \frac{1}{2}(4)(2)^2 = \frac{1}{2}(64)x^2 \quad \Rightarrow x = \frac{1}{2}\text{ m}$$

$$v = 2\,\frac{\text{m}}{\text{s}}$$

61. The answer is C. The magnetic field does no work, so the speed is constant. The motion path is a helix because there are velocity components both parallel and perpendicular to the field.

62. The answer is C. The flux out of the page through the loop is decreasing, so a counterclockwise current must flow to try to keep it from changing. The segment closest to the long wire then feels an attractive force. Since you have a changing magnetic field, an electric field is created as well.

63. The answer is A. Use the continuity equation to determine the speed in the wider pipe, and then use Bernoulli's equation to find the pressure.

$$v' = v\frac{A}{A'} = v\frac{r^2}{r'^2} = \frac{v}{4}$$

$$\frac{1}{2}\rho v^2 + P = \frac{1}{2}\rho v'^2 + P'$$

$$P' - P = \frac{1}{2}\rho v^2\left(1 - \frac{1}{16}\right)$$

64. The answer is E. For an ideal gas, $\frac{1}{2}mv^2 = \frac{3}{2}kT$, so doubling T increases v by $\sqrt{2}$.

65. The answer is C. The efficiency is $e = 1 - \frac{200}{600} = \frac{2}{3}$. One-third of the input energy is expelled, so 300 MJ must be the input, and 200 J of work are performed every hour.

66. The answer is B. For an elliptical orbit, the radius changes, so all the other quantities will change. The gravitational force exerts no torque since it acts toward the origin (the Sun), so angular momentum will stay the same.

67. The answer is D. Torque has dimensions of (force) × (distance), the same as energy. D has dimensions of (mass) × (velocity)^2—energy.

68. The answer is C. There will be a mass $2m$ oscillating on a spring with constant k. The time to reach maximum compression will be $\frac{1}{4}T$.

$$\frac{1}{4}T = \frac{1}{4}2\pi\sqrt{\frac{2m}{k}}$$

69. The answer is D. The reaction equation is

$$^{3}_{2}\text{He} + ^{3}_{2}\text{He} \rightarrow 2^{1}_{1}\text{p} + ^{A}_{Z}?$$

Balancing the top and bottom gives $Z = 2$, $A = 4$.

70. The answer is D. The nucleus consists of 2 protons and 1 neutron. The binding energy of the nucleus lowers its mass to be less than the sum of the individual components.

1 B Free-Response Explanations

1. (a) Use energy conservation to find the KE and the velocity of the mass after it leaves the spring.

$$E_i = E_f$$

$$E_i = \frac{1}{2}kx^2 = \frac{1}{2}(200)(0.5)^2 = 25\text{ J}$$

$$\frac{1}{2}kx^2 = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{k}{m}}x = \sqrt{\frac{200}{0.5}}(0.5) = 10\ \frac{\text{m}}{\text{s}}$$

(b) The impulse delivered to the 2 kg mass will equal its change in momentum and can be determined from the area under the F vs. t graph given. There are two equal triangles and a rectangle.

$$\Delta p = J = \text{area}$$

$$mV - 0 = 2\left[\frac{1}{2}(2.5 \times 10^{-3})(480)\right] + (10 \times 10^{-3})(480) = 6\text{ N} \cdot \text{s}$$

$$2V = 6$$

$$V = 3\ \frac{\text{m}}{\text{s}}$$

(c) To find the final energy of the system, you need to use momentum conservation to find the final velocity of the smaller mass.

$$P_i = P_f$$

$$0.5(10) = 2(3) + 0.5v' \quad \Rightarrow \quad v' = -2\ \frac{\text{m}}{\text{s}}$$

$$\Delta E = E_f - E_i$$

$$\Delta E = \left[\frac{1}{2}(0.5)(-2)^2 + \frac{1}{2}(2)(3)^2\right] - 25 = -15\text{ J}$$

(d) The 2 kg mass will go directly over the edge of the table. The 0.5 kg mass rebounds first into the spring, but since the spring force is conservative, the mass will leave the spring with the same speed, 2 m/s, and eventually go over the edge as well. Both masses take the same time to hit the ground after they leave the table, since they have no initial vertical velocity.

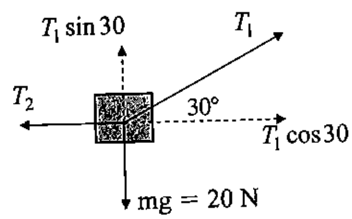
$$\Delta y = \frac{1}{2}gt^2 \qquad \Delta y = 1 \text{ m}$$

$$t = \sqrt{\frac{2\Delta y}{g}} = 0.45 \text{ s}$$

$$\Delta x_{2\text{kg}} = Vt = 3(0.45) = 1.35 \text{ m}$$

$$\Delta x_{0.5\text{kg}} = v't = 2(0.45) = 0.90 \text{ m}$$

They hit 0.45 m apart.



2. (a) Since this is an equilibrium situation, $netF = 0$. Therefore the net force in the x-direction equals zero and the net force in the y-direction equal to zero. Using the figure, you find:

x-component	y-component
$T_1 \cos 30 = T_2$	$T_1 \sin 30 = 20$

From the y-component, you get $T_1 = 40$ N. Substituting T_1 in the first equation, you get $T_2 = 34.6$ N.

(b) Use energy conservation, since the tension does no work on the mass as it descends. The initial height is $h = 3 - 3\cos 60 = 1.5$ m.

$$E_i = mgh = E_f = \frac{1}{2}mv^2$$

$$v = \sqrt{2gh} = \sqrt{30} = 5.5 \frac{\text{m}}{\text{s}}$$

(c) The mass is moving in a circular arc, so use Newton's second law and the centripetal acceleration formula.

$$netF = ma = m\frac{v^2}{R} = 2\frac{30}{3} = 20 \text{ N}$$

$$T - mg = 20$$

$$T = 40 \text{ N}$$

(d) Use momentum conservation.

$$2(5.5) = 4v' \quad \Rightarrow v' = 2.75\ \frac{\text{m}}{\text{s}}$$

(e) Kinetic energy is not conserved. One can explicitly calculate the KE before and after and see that they are different. The KE just before collision will equal the initial PE since the string does no work.

$$\Delta K = \frac{1}{2}(2m)v'^2 - mgh = 2(2.75)^2 - 20(1.5) = -14.9\text{ J}$$

The loss of energy occurs because work is done by internal forces within the bodies producing thermal energy, deformation, and sound.

3. (a) Use energy conservation.

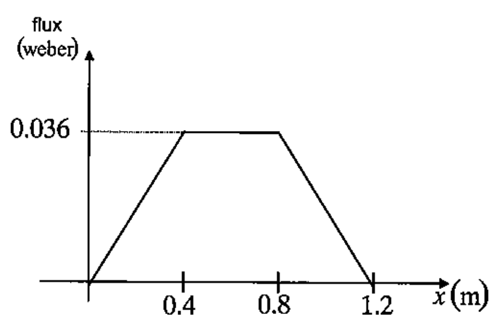
$$\frac{1}{2}kx^2 = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{k}{m}}x = \sqrt{\frac{100}{0.25}}(0.3) = 6\ \frac{\text{m}}{\text{s}}$$

(b) For the moving rail, the induced voltage is

$$V = BLv = (0.2)(0.4)(6) = 0.48\text{ V}$$

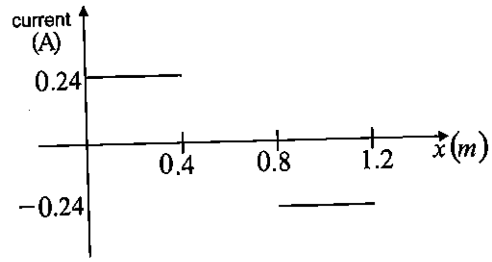
(c) The flux rises linearly from 0 to B (area) = 0.032 weber over the first 0.4 m. It then remains constant at this value for the next 0.4 m, and finally decreases linearly to 0 over the last 0.4 m.



(d) While the loop is entering the field region, the current will be given by Ohm's law.

$$i = \frac{V}{R} = \frac{0.48}{2} = 0.24\text{ A}$$

Since the flux is increasing, the current will make its own field to oppose this, creating a field out of the page. The loop right-hand rule then tells you that the current flows counterclockwise. There is no flux change over the second 0.4 m, so no current is induced. As the loop leaves the field region, the same magnitude of current is induced. Now the flux is decreasing, so the induced current will flow to make a field that points into the page, implying a clockwise current.



4. (a) Since the power supplied equals the power consumed by the bulb, you have

$$P = i^2R \qquad \Rightarrow E_{supplied} = i^2Rt$$

(b) Bulb A, connected in parallel with the battery, will have the same current i. The other three bulbs can be treated as a separate loop. Their effective resistance is $\frac{3}{2}R$ since the two in parallel have resistance $\frac{1}{2}R$. That means the current in bulb B is $\frac{2}{3}i$, and both C and D will have $\frac{1}{3}i$.

(c) The brightness will be proportional to the power consumed by the bulbs. The power dissipation of each bulb is

A	B	C	D
i^2R	$\left(\frac{2}{3}i\right)^2R = \frac{4}{9}i^2R$	$\left(\frac{1}{3}i\right)^2R = \frac{1}{9}i^2R$	$\left(\frac{1}{3}i\right)^2R = \frac{1}{9}i^2R$

A has the same brightness, B is $\frac{4}{9}$ as bright, and both C and D are $\frac{1}{9}$ as bright.

(d) (i) If A fails, there is no effect on the other bulbs because they have the same voltage applied across them.

(ii) If C fails, A is unaffected. Now B and D are in series in the outer loop. Since their resistance is now effectively $2R$, the current in these bulbs will be $\frac{1}{2}i$, and the power they consume will be $\left(\frac{1}{2}i\right)^2 R = \frac{1}{4}i^2R$. They will be $\frac{1}{4}$ as bright as the single bulb circuit.

5. (a) You can use the photoelectric effect energy equation in eV energy units.

$$KE = \frac{hc}{\lambda} - \phi$$

$$1.85 = \frac{1{,}240}{480} - \phi \quad \Rightarrow \phi = 0.73 \text{ eV}$$

(b) At threshold, the photon energy equals the work function.

$$\frac{hc}{\lambda_{th}} = \phi$$

$$\lambda_{th} = \frac{1{,}240}{0.73} \quad \Rightarrow \lambda_{th} = 1{,}698 \text{ nm}$$

(c) Now that you know the work function, you can use the energy relation again.

$$KE = \frac{hc}{\lambda} - \phi$$

$$3 = \frac{1{,}240}{\lambda} - 0.73 \quad \Rightarrow \lambda = 332 \text{ nm}$$

(d) The energy of the ejected electrons will be 3 eV. To find the De Broglie wavelength, rearrange the De Broglie formula (be careful of units).

$$E_{electron} = \frac{p^2}{2m} \quad \Rightarrow p = \sqrt{2mE_{electron}}$$

$$E_{electron} = 3(1.6 \times 10^{-19}) = 4.8 \times 10^{-19} \text{ J}$$

$$\lambda = \frac{h}{p} = \frac{6.6 \times 10^{-34}}{\sqrt{2(9 \times 10^{-31})(4.8 \times 10^{-19})}} = 7.1 \times 10^{-10} \text{ m}$$

(e) To see the effects of the electron wavelength, you need a "grating" with spacing on the order of the wavelength. This is comparable to the spacing in salt crystals, so you could direct this beam at such a crystal and look for the interference pattern, clear evidence of wave properties.

6. (a) There are 6 N-A intervals, each $\frac{1}{4}\lambda$, so

$$6\left(\frac{\lambda}{4}\right) = 1.5 \qquad \lambda = 1 \text{ m}$$

(b) Since the wave is periodic and its frequency is the same as the oscillator, you have

$$v_w = \lambda f = (1)(100) = 100 \ \frac{\text{m}}{\text{s}}$$

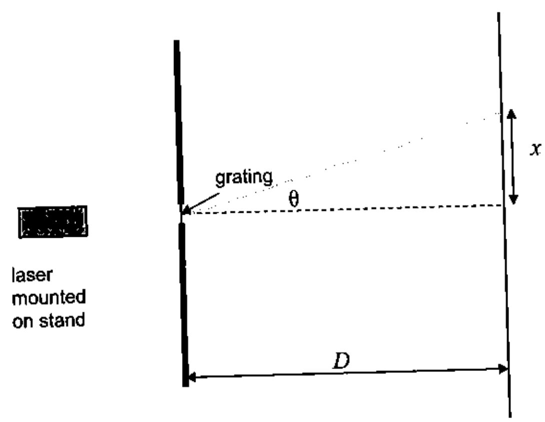
(c) Since the endpoints are fixed, the fundamental mode with the lowest frequency will have a single antinode, and the wavelength will be 3 m. The wave speed will be the same, since it's determined by the string mass and tension. Then for this standing wave, you have

$$f = \frac{v_w}{\lambda} = \frac{100}{3} = 33.3 \text{ Hz}$$

(d) Increasing the mass will increase the wave speed on the string. As the mass is increased holding the frequency fixed, the standing wave pattern will disappear fairly quickly since it's a resonance; as you change the wave speed, you change the natural frequencies of the string. Since $v_w = \lambda f$, the wavelength of the string wave will increase as well. As you continue to increase the mass, you eventually increase the wavelength enough so that 4 N-A intervals are set up on the string, and you're back at a resonance condition.

7. (a) stand for mounting laser, meter stick, paper or screen

(b)



(c) Align the laser so that light can pass through the known grating. Set up a screen a distance D behind the grating. Make D large enough so that the first order maxima have separated appreciably from the central maximum. Measure x, the distance from the central maximum to the first order maximum. This will allow you to determine θ, and you can then use the interference equation to determine λ, since the spacing can be determined from the given data. Once λ has been determined, replace the known grating with the unknown one. Make the same measurements of the interference pattern, determine θ, and now use the interference equation to determine the unknown spacing.

(d) For the known grating, $a = \frac{2.5 \times 10^{-3}}{80} = 3.13 \times 10^{-5}$ m. Determine the angle from

$$\tan\theta = \frac{x}{D}$$

The interference equation for the first order maximum then yields

$$a\sin\theta = \lambda \qquad \text{solve for } \lambda$$

Once λ is known, you can insert the unknown grating and obtain measurements of D' and x' with your meter stick. Then find θ' using:

$$\tan\theta' = \frac{x'}{D'}.$$

Then the interference equation gives you

$$a' = \frac{\lambda}{\sin\theta'}.$$